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Original article

Duration, frequency, and types of children's activities: Potential of a classification procedure

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Abstract

This study investigated the potential of a classification procedure to determine type, duration, and frequency of children's physical activity (PA) during 7 days based on accelerometer data. Hip and wrist accelerometer data (1-second epoch) were collected over a week in 41 children (age: 10.7 ± 0.9 years). The classification procedure was used to assign each second into one of the following four categories: stationary activities, walking, running, and jumping. A diary was used to assess the simultaneous activity setting. Children spent 75.5% of the time (600.9 ± 80.1 minutes/day) on stationary activities, 15.6% (124.6 ± 33.6 minutes/day) on walking, 2% (16.1 ± 8.6 minutes/day) on running, and 1% (4.7 ± 5.2 minutes/day) on jumping. The median duration of stationary activities, walking, running, and jumping was 4, 2, 1, and 1 seconds, respectively. The largest proportion of running and jumping occurred during outdoor sport training (10.7%), physical education classes (6.7%), and vigorous outdoor activity (6.1%). The classification procedure used in this study shows the potential for analyzing children's PA in free-living conditions. The study results revealed that children's PA is characterized by very short activity bouts and that providing the possibility for children to participate in structured or unstructured outdoor activities might increase their PA. Therefore, the classification procedure enhanced the analysis of the transitory nature of children's PA and the understanding of their PA behavior during different activity settings.

Keywords: Accelerometer; Activity; Child; Classification; Physical

Introduction

Physical activity (PA) has been shown to be strongly and inversely associated with obesity,[1–3] insulin resistance,[4] and cardiovascular and metabolic diseases,[2–5] and positively associated with musculoskeletal health[6,7] and the psychological well-being of children.[8,9] Current PA guidelines state that children and adolescents should accumulate at least 60 minutes of moderate-to-vigorous PA daily.[10] Therefore, assessing the PA behavior in a free-living environment is important for understanding youth behavior and whether it meets the current PA guidelines, for quantifying the relationship between PA and health outcomes, and for determining the effectiveness of the interventions designed to increase PA in children.

In particular, accelerometers are widely used to quantify children's free-living PA and to estimate the average activity[1,4,11–13] or the amount of time spent in sedentary, light, moderate, and vigorous activities.[2,12,13] However, the use of cut-off points that determine the thresholds for these intensities has been discussed lately, as the points strongly depend on the types of activity that were used for their development, and they have been reported to underestimate unstructured household or play activities.[14–17] In addition, the metabolic equivalent task (MET) level standards for low, moderate, and vigorous activities have been debated for the use in children, as the MET values are different during a variety of activities when compared with adults.[18,19] Furthermore, the single energy expenditure

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prediction equations developed for a merged variety of activities that built the basis for the cut-off points did not estimate the energy expenditure of individual activities accurately.[14,20] Therefore, identifying the type of activities might not only be useful to describe the activity behavior of children, but will also be useful as a basis for activity-type-specific energy expenditure estimations that have been shown to be more precise than previous single prediction equations.[20] In addition, recognizing the type of activity is important for PA recommendations in regard to certain health factors. For example, for bone health, PA guidelines recommend that children perform high-impact types of activity, such as running, jumping, or playing games three times a week, because of their bone strengthening effects.[6,21]

Several studies have implemented classification techniques to identify the type of PA in children in the laboratory[22,23] or in the children's natural environment.[24] The latter provides, to our knowledge, the only validation in a free-living setting, which is crucial for the application in the field. The overall recognition rate of that study, validated in an independent sample, was 67% using a combination of hip and wrist accelerometer counts, which was higher than using a hip accelerometer only (44%). These recognition rates were lower than in other laboratory studies[22,23]; however, it has been shown that recognition rates decrease from laboratory to field conditions.[25] As activity-type classification systems have not been applied to accelerometer data collected in free-living conditions until now, the recognition rate of that classification procedure was considered as adequate to provide a first insight into the free-living activity behavior of children. Therefore, the aim of this study was to assess the use of a classification procedure that was previously validated in the field,[24] to analyze the type, duration, and frequency of children's free-living activities.

Methods

Study participants

The study participants were recruited from two Swiss elementary schools. All of the teachers ($n = 10$) responsible for the classes of children aged between 9 and 12 were contacted. Of these, four agreed that the parents of all the students in their classes could be contacted. Forty-five children agreed to participate in the study. The study was approved by the regional ethics committee, and the parents and the children gave their written informed consent.

Accelerometers

Two uniaxial accelerometers (GT1M; ActiGraph, LLC, Pensacola, FL, USA) were sent to each participant. These devices record 30 measurements/second and integrate these values continuously over time. The data are filtered with a band-pass filter and summed up over user-specific intervals. For this study, the data were recorded with a 1-second data epoch setting. The participants were asked to wear the accelerometers on an elastic belt on the right hip and on the dominant wrist in the morning after waking up and to take them off before going to bed for 7 consecutive days. Wearing the device on the hip was reported to be well tolerated by children when directly asked by an investigator. It was reported to be comfortable to wear and did not hinder any of their activities.[26] To our knowledge, the acceptance of the combination of a hip- and a wrist-worn device was not investigated in children previously. However, accelerometers worn on the hip have frequently been used in population-based studies,[1,2,4,5] indicating that the device is accepted well in children. The burden of an additional device worn on the wrist was accepted in consideration of the evidence-based field validity of the used system for activity-type classification. During the development of the presently used classification procedure, a higher recognition rate (67%) was reported using an additional device on the wrist in comparison with using a single device attached to the hip (44%).[24] The data of the accelerometers were downloaded using the respective software (ActiLife 6.0; ActiGraph, FL, USA).

Classification procedure

The classification procedure used in this study has been explained and validated elsewhere.[24] In brief, during the development of the procedure, video sequences were recorded by an unobtrusive observational system that was installed simultaneously at each child's home, school, during physical education (PE) lessons, or during free play to measure the accelerometer data. The vertical accelerometer counts from the hip and wrist devices without any additional features were synchronized and labeled by the activities found during the video sequences. With these data, a classification procedure was developed and tested on an independent sample. The development study showed that stationary activities were recognized at a high level (92.6%), whereas walking, running, and jumping were recognized at an adequate level (69.1%, 75.2%, and 70.9%, respectively) with a major vote classifier that merged the activity classification of three *a priori* classifiers. The remaining activities (floor exercise, biking, horseback riding, and crawling) were not recognized by this procedure (<0.001%).[24] In the present study, all activities that were not recognized by the major vote classifier as stationary, walking, running, or jumping were classified as not assigned.

Activity diary

During the study period, the children were instructed to record their weight, height, and the PA settings in a diary. At the end of each day of the measurement week, the children reported one of the 20 activity options for each 15-minute period. The activity diary provided 20 different activity settings and has recently been validated.[27] Correlation was previously reported as $r = 0.52$, when the diary categories for moderate to vigorous activity behavior were related to accelerometry.[27] Homework, reading, watching TV, sitting at a computer, eating, playing an instrument, and being at school were summarized into one activity class as "general low activities" (Fig. 3). To compare the activity settings found in the diary with the results of the classification procedure, both data sets were set alongside each other. Therefore, each second of a 15-minute period within a diary setting was investigated by determining its activity type according to the classification procedure. The activities found by the classification system within each diary setting were analyzed with regard to their absolute and proportional values of the total time spent in the specific setting.

Data analysis

The time when the child was awake was determined using an algorithm that determined the first and the last 5 minutes of consecutive counts over zeroes during the day. Bouts of zero counts that lasted at least 60 minutes during the time when the child was considered to be awake were excluded from the respective accelerometer as it was assumed that the participants did not wear the device during those times. Simultaneous data were excluded from the second device and from the diary data. Days with less than 8 hours of available activity data were excluded from the analysis, as it was assumed the accelerometer was not worn for most of the day. Criteria for including the accelerometer data were the full measurement of 3 weekdays and 1 weekend day. The duration and frequency of activity bouts (a period in which one activity type is performed without interruption by another activity type) were identified during the measurement period by the classification procedure. In each activity, the number of each bout between 1 and 60 seconds as well as for the bouts in the 60–70-, 71–80-, 81–90-, 91–120-, 121–180-, 181–300-, 301–600-, 601–1200-, and >1200-second period was counted. Type, duration, and frequency were analyzed on an average daily basis for each weekday separately and for each 2-hour period during the day from 6 to 22 hours. Each activity type in this study was analyzed simultaneously by the cut-off thresholds developed by Puyau et al[17] that were extrapolated for the use with 1-second data.

Mean and standard deviations were used to report the absolute and relative time spent in each activity class and their frequency as recognized in the accelerometer data by the classification procedure and in the diary. As the duration of the different types of activity recognized by the classification procedure was skewed, the median and the 95% confidence interval were used for descriptive analysis. A general linear model for repeated measures with the Bonferroni correction for multiple comparisons was used to identify differences in frequency and absolute time spent in the activity types between each day of the week and to compare the time found in the different activity settings of the diary between weekdays. The same procedure was performed for the proportion of daytime spent in each activity type. The Friedman test was used to investigate differences in the duration of activities between the different weekdays. Principal component analysis was performed to find similar periods during the day regarding the proportion of daytime spent in different activity types. All standard statistical analysis was performed using SPSS 19 (SPSS Inc., Chicago, IL, USA). All classification procedures were carried out using MATLAB R2011b (MathWorks, Natick, MA, USA).

Results

Daily activity

Data of four children had to be excluded from the data analysis as the criteria for the number of valid days were not fulfilled: short wear time ($n = 3$) or the data loss due to technical problems was too high ($n = 1$). The characteristics of the remaining 41 participants are presented in Table 1. Two children had missing hip and wrist data on two days. In a third child, 3 days had missing data, twice in both the devices and once in the wrist device alone. In total, 141 (6.7 days/child) days were included in the analysis. The classification procedure classified the largest part of the hip and wrist accelerometer data registered during an ordinary school week as stationary activities (600.9 ± 80.1 minutes/day, 75.5%). The procedure recognized 124.6 ± 33.6 minutes/day (15.6%), 16.1 ± 8.6 minutes/day (2.0%), and 4.7 ± 5.2 minutes/day (0.6%) as walking, running, and jumping, respectively. The category “not assigned” contained 6.3% of the data (50.4 ± 16.0 minutes/day). Regardless of length, the classification procedure recognized 2329.4 ± 570.9 bouts/day as stationary, 2466.2 ± 671.9 bouts/day as walking, 486.0 ± 224.0 bouts/day as running, and 154.7 ± 107.0 bouts/day as jumping. The procedure found a median duration of 4 seconds for stationary, 2 seconds for walking, and 1 second for running as well as for jumping activities. Further, the classification system revealed that 95% of all stationary activities lasted less than 60 seconds (Fig. 1). Ninety-five percent of all walking bouts identified by the classification procedure lasted 8 seconds or less; 95% of all running bouts lasted 5 seconds or less; and 95% of all jumping bouts lasted a maximum of 4 seconds for all children. The classification of each activity type with the cut-off method into sedentary, light, moderate, and vigorous activity is shown in Table 2. Stationary activity was classified as sedentary activity by the cut-off method. Walking, running, and jumping were mainly classified as light, moderate, and vigorous activity, respectively.

Activity on weekdays

The classification procedure found significant global differences between the weekdays regarding the time spent in the activity types, namely, stationary, walking, and running ($p < 0.001$). Children spent significantly more absolute daytime in stationary activities, walking, and running during most of the weekdays compared with weekends ($p < 0.05$; Table 3). However, the proportion of daytime spent in stationary

Table 1
Characteristics of participating children.

	Girls ($n = 24$)	Boys ($n = 17$)
Age (y)	10.7 ± 1.1	10.6 ± 1.2
Height (m)	1.5 ± 0.1	1.5 ± 0.1
Weight (kg)	38.4 ± 8.6	39.7 ± 8.5
BMI (kg/m^2)	16.9 ± 1.8	17.7 ± 2.5

BMI = body mass index.

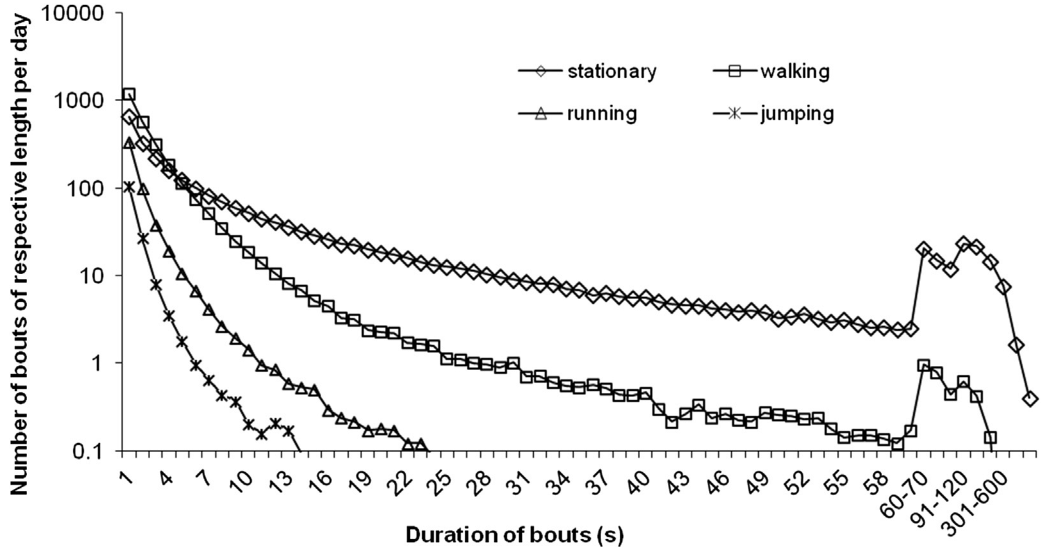

Fig. 1. Number of bouts found in stationary activities, walking, running, and jumping according to their duration ($n = 41$).

Table 2
Proportions of each activity type classified into intensity levels by the cut-off method.[15]

	Sedentary	Light	Moderate	Vigorous
Stationary	100	0	0	0
Walking	21.2	59.4	19.4	0
Running	0.7	2.2	87.1	10
Jumping	0	0	0	100
Not assigned	83	7.2	9.7	0.1

activities, walking, and jumping was not significantly different between days. The proportion of daytime spent running was significantly higher on Monday and on Wednesday than on Sunday and Thursday ($p < 0.05$). No significant differences between weekdays and weekends were found for absolute and relative daytime spent in the activities classified as "not assigned." The frequency of bouts significantly differed in all activities on several weekdays from that performed on a Sunday ($p < 0.05$). However, there were no significant differences between the frequency of bouts of any of the activities between Saturday and Sunday. No significant differences were found for the duration of the activities over the other

Table 3
Time, proportion, frequency, and duration of activities during daytime of each day of the measurement week ($n = 41$).

		Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Stationary	% of Wear time (min)	74.7 (607.9 ± 60.2)	76.2 (628.1 ± 54.5)	73.5 (610.1 ± 69.9)	75.6 (628.5 ± 65.1)	75.4 (648.5 ± 92.3)	75.9 (564.2 ± 136.7)	77.2 (519.2 ± 81.8)
	Frequency	2541.0 ± 503.3[a]	2403.6 ± 356.0[a]	2465.2 ± 399.9[a]	2427.9 ± 457.1[a]	2522.9 ± 599.0[a]	2247.4 ± 802.9	1697.7 ± 878.3
	Duration (s)[b]	4 (1,52)	5 (1,59)	4 (1,54)	4 (1,55)	4 (1,54)	4 (1,51)	4 (1,58)
Walking	% of Daytime (min)	16.4 (133.1 ± 27.1)	15.4 (127.1 ± 26.2)	17.0[a] (140.8 ± 32.0)	15.5 (129.1 ± 24.7)	16.0 (137.3 ± 36.6)	14.7 (109.8 ± 40.9)	14.2 (95.2 ± 47.7)
	Frequency	2744.3 ± 457.2[a]	2576.0 ± 506.3[a]	2729.5 ± 586.2[a]	2509.0 ± 498.2	2750.1 ± 767.9[a]	2256.5 ± 891.7	1697.7 ± 995.9
	Duration (s)[b]	2 (1,8)	2 (1,8)	2 (1,8)	2 (1,8)	2 (1, 8)	2 (1, 7)	2 (1,7)
Running	% of Daytime (min)	2.4[a,c] (19.8 ± 9.6)	1.9 (15.5 ± 6.5)	2.4[a,c] (20.3 ± 10.5)	1.9 (15.8 ± 5.4)	2.0 (17.5 ± 8.1)	1.7 (12.8 ± 11.1)	1.6 (11.1 ± 8.9)
	Frequency	608.1 ± 207.2[a,c,d]	497.5 ± 190.9[a]	594.2 ± 282.3[a,d]	461.7 ± 167.4	556.3 ± 243.2[a]	376.7 ± 229.9	307.2 ± 247.2
	Duration (s)[b]	1 (1,5)	1 (1,5)	1 (1,5)	1 (1,5)	1 (1,4)	1 (1,5)	1 (1,4)
Jumping	% of daytime (min)	0.6 (5.0 ± 3.6)	0.5 (4.5 ± 6.5)	0.7 (5.8 ± 4.4)	0.6 (5.0 ± 4.2)	0.6 (5.4 ± 6.3)	0.5 (4.0 ± 8.1)	0.5 (3.2 ± 3.0)
	Frequency	206.3 ± 143.0[a,d]	146.7 ± 114.8	199.0 ± 124.4[a,d]	155.8 ± 97.4	173.2 ± 120.9[a]	108.2 ± 60.1	94.0 ± 88.3
	Duration (s)[b]	1 (1,3)	1 (1,5)	1 (1,4)	1 (1,4)	1 (1,4)	1 (1,4)	1 (1,3)
Not assigned	% of daytime (min)	5.9 (48.1 ± 16.0)	6.0 (49.3 ± 12.7)	6.4 (52.9 ± 13.6)	6.4 (53.6 ± 17.3)	6.0 (51.7 ± 15.3)	7.2 (53.9 ± 19.2)	6.5 (43.4 ± 16.9)
	Frequency	2263.8 ± 662.3	2137.6 ± 472.8	2245.5 ± 542.7[a]	2156.2 ± 577.2	2221.2 ± 614.8[a]	2095.2 ± 800.8	1618.4 ± 884.3
	Duration (s)[b]	1 (1,3)	1 (1,3)	1 (1,3)	1 (1,3)	1 (1,3)	1 (1,4)	1 (1,3)

Wear time = time when the accelerometer was worn.
[a] Significantly higher than Sunday ($p < 0.05$).
[b] Values are medians and 95% confidence intervals.
[c] Significantly different from Thursday ($p < 0.05$).
[d] Significantly higher than Saturday ($p < 0.05$).

Table 4
Amount of time spent in selected activities assessed with the activity diary ($n = 41$).

	Monday (min/d)	Tuesday (min/d)	Wednesday (min/d)	Thursday (min/d)	Friday (min/d)	Saturday (min/d)	Sunday (min/d)
School lessons	236.9 ± 95.0[a]	315.4 ± 66.1[b,c]	197.4 ± 55.9[a]	261.2 ± 46.7[a,b]	234.9 ± 74.9	—	—
PE lessons	37.3 ± 19.0[b,c]	27.1 ± 24.7[c]	12.8 ± 20.3	31.1 ± 24.7[c]	4.4 ± 22.1	—	—
Vigorous indoor activity	1.8 ± 6.0	5.9 ± 13.8	9.9 ± 25.2	4.0 ± 14.2	7.7 ± 27.3	11.0 ± 36.1	3.7 ± 12.5
Vigorous outdoor activity	9.1 ± 20.9	10.2 ± 27.3	19.8 ± 41.4	21.6 ± 37.7	22.7 ± 55.9	28.5 ± 53.9	45.4 ± 87.5
Indoor sport training	15.7 ± 35.8	11.0 ± 27.5	18.3 ± 33.0	13.5 ± 35.3	3.7 ± 17.7	2.2 ± 10.4	1.8 ± 9.6
Outdoor sport training	10.5 ± 31.1	2.2 ± 14.1	28.2 ± 66.3	9.1 ± 30.0	10.6 ± 37.7	22.3 ± 61.6	3.3 ± 15.6

PE = physical education.
[a] Significantly different to Tuesday.
[b] Significantly different to Wednesday.
[c] Significantly different to Friday.

days. According to the diary, Wednesday contained significantly fewer school lessons (197.4 ± 55.9 minutes/day) than Tuesday and Thursday (≥261.2 minutes/day) ($p < 0.05$; Table 4). Significantly more time was spent in PE classes on Monday (37.3 ± 19.0 minutes/day) than on Wednesday and Friday (≤12.8 minutes/day; $p < 0.05$). There was no significant difference in the time spent in vigorous indoor activity on the different weekdays. Time spent in vigorous outdoor activity varied among the days with Saturday and Sunday containing the highest amounts; however, large variations within the children led to no significant differences between days. Most of the indoor and outdoor sports training (28.2 ± 66.3 minutes/day) was performed on Wednesday. However, as there was a large variability within the children, the amount of outdoor sports training was not significantly elevated compared with other school days.

Within-day variability

All types of activity were explained by three distinct components, and running by two major distinct components. These components explained 68.3%, 76.8%, 49.9%, and 69.9% of the variance of stationary activity, walking, running, and jumping, respectively. The relative amount of stationary activity from 8:00 to 10:00 AM was similar to that from 4:00 to 6:00 PM (Fig. 2). Similar periods appeared in the early morning

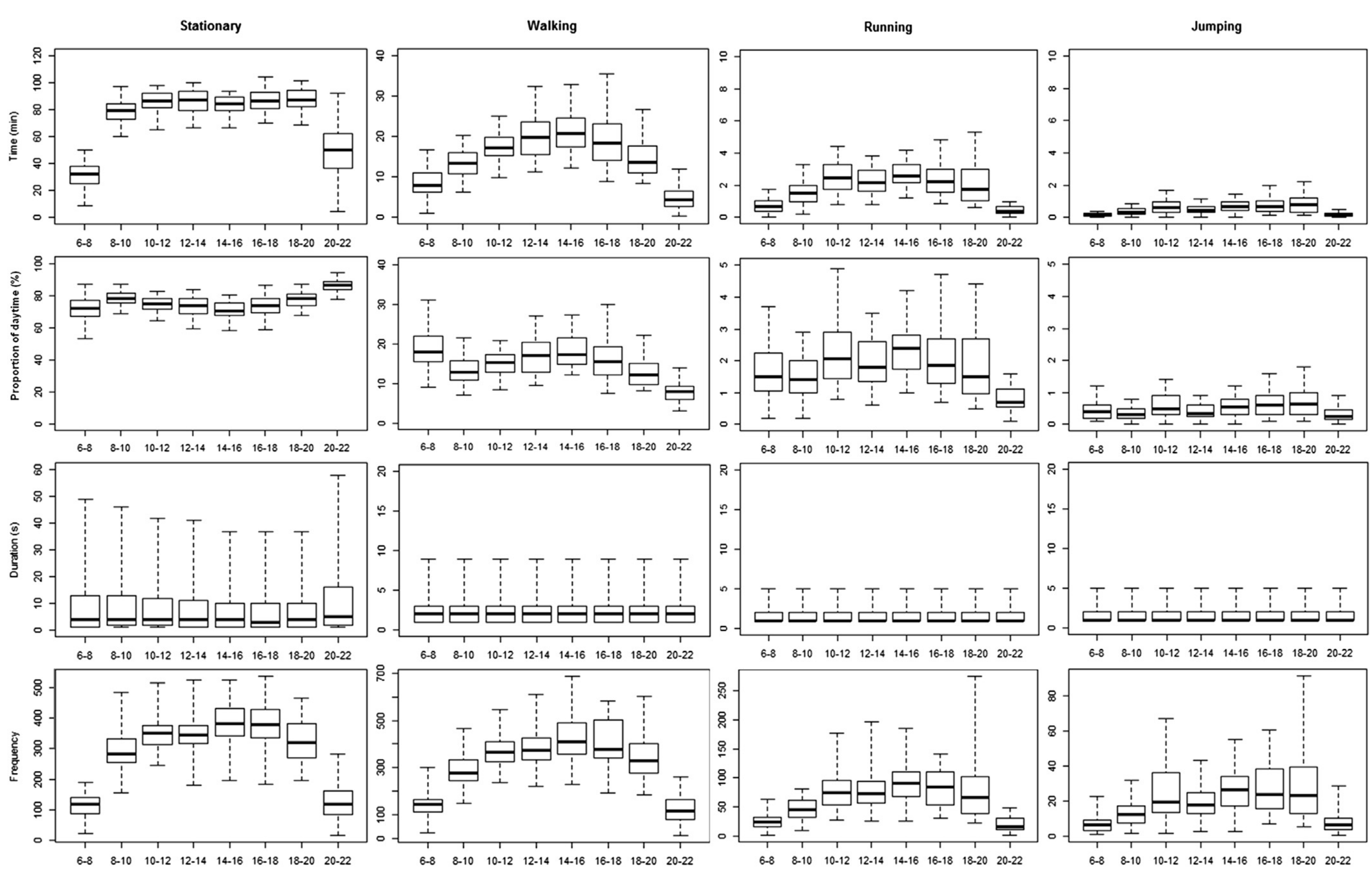

Fig. 2. Time, proportion, duration, and frequency of stationary activities, walking, running, and jumping for each 2-hour period between 6:00 AM and 10:00 PM ($n = 41$) averaged over all weekdays.

(6:00–8:00 AM) and during mid-morning until the afternoon (10:00 AM to 4:00 PM). A third component appeared during the evening (6:00–10:00 PM). Walking activities seem to be similar in the early morning (6:00–8:00 AM) and from 12:00 to 2:00 PM Another distinct component was found during the morning (8:00 AM to 12:00 PM) and afternoon (2:00–6:00 PM). Walking in the evening (6:00–10:00 PM) was different from all other periods. Running was similar in the morning (6:00–10:00 AM), around lunchtime (12:00–2:00 PM), and during the evening (6:00–10:00 PM). A second component seems to exist during the late morning (10:00–12:00 PM) and afternoon (2:00–6:00 PM). Jumping was similar during the afternoon sections (2:00–6:00 PM). Similar periods appeared in the morning (6:00–10:00 AM), during midday (12:00–2:00 PM), and late evening sections (8:00–10:00 PM). Late morning periods (10:00 AM to 12:00 PM) seem to be similar to early evening periods (6:00–8:00 PM) regarding jumping (Fig. 2). The analysis of the diary settings revealed that 28.0% of all PE lessons took place between 10:00 AM and 12:00 PM, and 24.8% between 2:00 and 4:00 PM (Fig. 3). The remaining time was spent in lessons taking place between 6:00 and 10:00 AM Only 1% of the time spent in PE lessons was found after 4:00 PM; 49.7% of the school breaks were found between 8:00 and 10:00 AM; and 41.4% between 10:00 and 12:00 AM Highest levels of vigorous indoor activities were found between 12:00 and 2:00 PM (27.9%) and between 6:00 and 8:00 PM (24.0%). Highest amounts of time spent in vigorous outdoor activity were found between 2:00 and 4:00 PM (29.3%) and between 4:00 and 6:00 PM (33.3%). A total of 47.9% and 35.8% of the time spent in indoor and outdoor sport training, respectively, were found between 6:00 and 8:00 PM; 15.8%, 17.9%, 23.6, and 20.9% of the time spent in walking was found between 6:00 and 8:00 AM, between 10:00 and 12:00 AM, between 12:00 AM and 2:00 PM, and between 2:00 and 4:00 PM, respectively.

Description of the activity diary settings by classification procedure

Upon comparing the diary-recorded activities with the classification results from the accelerometer, the largest proportion of running and jumping occurred during outdoor sport training (10.7%), PE classes (6.7%), and vigorous outdoor activity (6.1%) (Fig. 4). Absolute values spent in walking, running, and jumping during PE, vigorous outdoor activity, and outdoor sport training were 26, 48, and 27 minutes/week, respectively. During vigorous indoor activity, 10 minutes/week were spent on walking, running, or jumping. The highest absolute levels in walking (383.9 minutes/week), running (50.1 minutes/week), and jumping (13.6 minutes/week) were achieved in the general low activities class. The highest levels of walking (159.5 minutes/week), running (23.3 minutes/week), and jumping (5.2 minutes/week) were all achieved during school. The high levels of walking (24.1%) as recorded by the accelerometer coincided with the diary-recorded walking activity. In total, 107.6 minutes of walking, 12.1 minutes of running, and 2.3 minutes of jumping were found during the time when the child filled in "walking" in the activity diary.

Discussion

This study demonstrated the potential of applying a classification procedure to accelerometer data to analyze children's free-living activities. The classification system recognized different types of activities, their duration, and frequency, and therefore provided different information on the

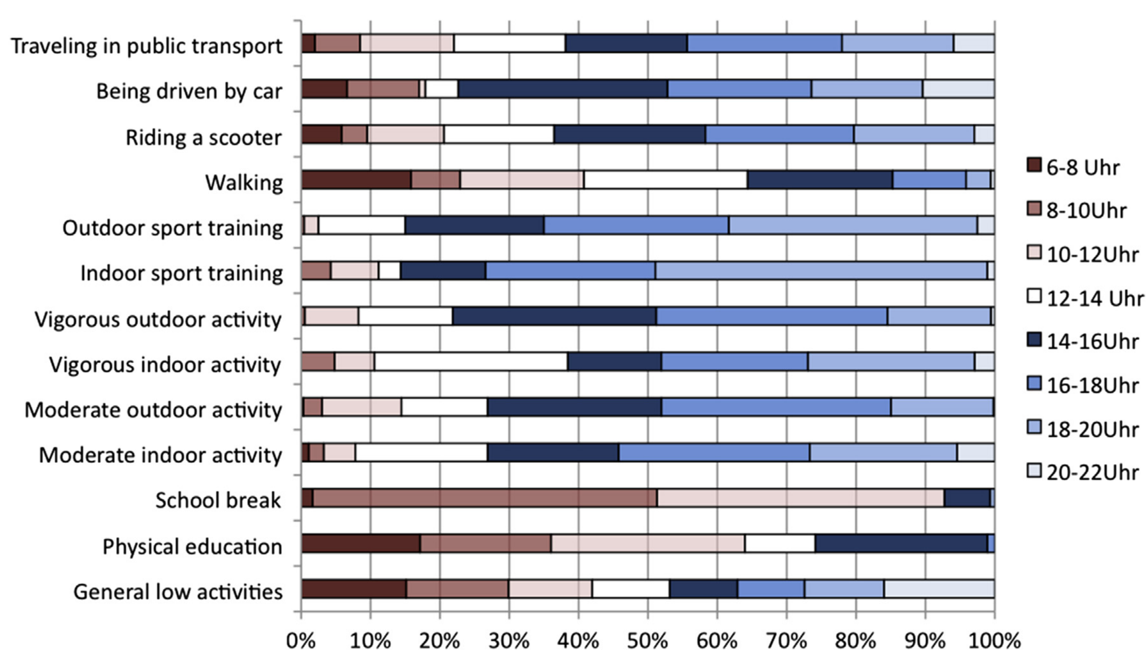

Fig. 3. Proportion of time spent in each activity diary setting for each 2-hour period between 6:00 AM and 10:00 PM ($n = 41$).

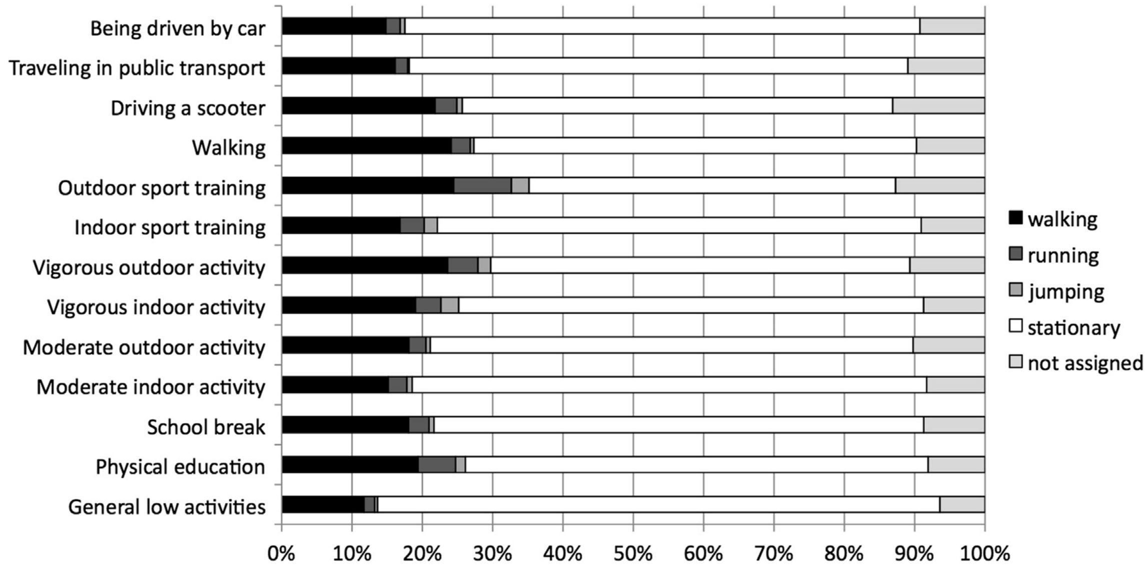

Fig. 4. Proportion of time spent in stationary activities, walking, running, and jumping during each activity diary setting.

children's PA behavior than previous cut-off methods used for analyzing the intensity of activities. The classification procedure confirmed that children spend a large proportion of the daytime performing stationary activities and performed more intense activity types for very short periods. It showed potential for the detailed investigation of different activity settings assessed by a diary, which might be important for describing the PA behavior of children or for interventions focusing on particular settings. Therefore, this study enhanced the understanding of different aspects of activity on different weekdays and at different periods of the day and during various activity settings by applying a classification procedure to accelerometer data.

Daily activity

To the best of our knowledge, the results of this study can be compared only to one study that presented information on children's PA to a similar degree of detail.[28] The authors of that study reported that the percentage of time spent in low activities (sitting, standing, kneeling, and lying) was 73%, and the participants spent 16.2%, 2%, and 0.3% of the time walking, running, and jumping, respectively. The median duration of low and moderate intensity was 6 seconds, and the median duration of vigorous activities was 3 seconds.[28] In our study, the proportion of daytime spent on walking, running, and jumping was similar. Nevertheless, the median duration of the activities was shorter (4 seconds for stationary activities, 2 seconds for walking, 1 second for running, and 1 second for jumping) than that reported previously (3 seconds).[28] These results were supported by Baquet et al (2007) who investigated the length of light, moderate, vigorous, and high-intensity activities measured with accelerometers.[29] They reported that around 93% of all vigorous bouts and 96% of all very high-intensity bouts were less than 10 seconds in duration. The shorter activity duration found in our study was probably due to the high sampling rate set at 1-second epochs, allowing more precise quantification of the highly intermittent and rapid changes in children's PA. The classification of stationary activities, walking, running, and jumping into sedentary, light, moderate, and vigorous activity by the cut-off method was comparable with the findings of the development study.[24] Walking was assigned to several intensity classes underlining the different focus (activity type vs. intensity) of the two methods. The classification of running into moderate activity indicates most likely the dependence of the cut-off thresholds to the activities used during development.[17] The category "not assigned" contained 50 minutes of data in the present study. This is three times the amount of time spent in running and jumping combined and 40% of the time spent walking. However, most of the time was spent in sedentary or low activity and only 9.8% (4.9 minutes) of the not assigned time of the whole week in the present study was spent on moderate-to-vigorous activities. Therefore, the time recognized as not assigned seems not to increase the health-related activity relevantly. However, activities generating low accelerations such as cycling may have been classified as low activities. As the classification procedure classified cycling to a large part as "not assigned",[24] it is possible that the amount of moderate-to-vigorous activities within the not-assigned category might actually be higher than found in the present study. A classification procedure, as presented in this study, demonstrates that the duration of different types of children's activities might be shorter than reported earlier, most probably because this procedure allows an analysis of the PA in children on a higher resolution than in observational studies. It provides corresponding information on type, frequency, and duration in a manner similar to an observational method with lower cost in time, but in more detail; in addition, it also provides additional information such as the type of activity compared with cut-off methods that focus on activity intensity.

Between-day variability

The classification procedure offers the analysis of the time, duration, and frequency of activity types such as stationary, walking, running, and jumping on different weekdays. Differences in time spent in the different activities across days seemed to be down to frequency of activities without any differences in the duration. The procedure reveals that more absolute time is spent walking and running on weekdays than on weekend days. However, these differences were evident only in the running activity when the proportion of daytime spent in the activities was analyzed. Therefore, the main differences in activity between school and weekend days result from the length of the wear time of the accelerometer. The low absolute values and the low relative values in running lead to the assumption of a less active weekend in line with previous literature,[30,31] suggesting that the long sleeping hours on weekends decrease the activities. Vigorous indoor and outdoor activities and indoor and outdoor sport training were not increased on weekends in comparison to other weekdays when assessed with the diary. In detail, highest average levels of vigorous outdoor activity were achieved at the weekend but the large variation between the children did not lead to significant differences between days. Therefore, families do not consistently encourage their children to engage in active play outdoors on weekends to compensate for the short wear time of the monitor, which explains the short wear time when the children were awake. However, it is possible that children wore the monitor less reliably on the weekends, meaning that they put it on later after waking up and removed it earlier before going to bed.

Wednesday was the most active day according to the classification system and contained a lot of walking and running. This was probably influenced by the low amount of school time on this day according to the diary, and was supported by a lot of outdoor sport training taking place on Wednesday. The analysis of outdoor sport training by the classification procedure revealed a high proportion of running and jumping, which may have accounted for the increased active time on Wednesday. This is in line with previous literature that showed that average accelerometer counts were very high during outdoor sport training.[27] Monday was an active day according to the classification procedure, which might be due to frequent PE lessons on Monday according to the activity diary. When PE as a diary setting was analyzed by the classification procedure, it contained high amounts of walking, running, and jumping, which might have increased the level of activity on days containing PE lessons. In conclusion, PE lessons and school-free time increase activity in children. During free time, outdoor sport training might be effective to increase children's PA. Interventions should be aimed at the weekends to encourage parents to let their children play freely or do sports training that increases PA in children.

Within-day variability

The within-day variability found in this study was mainly caused by a difference in the frequency of the activities and not by the duration of the activities. This was similar to the activity duration that did not change across days, indicating that increasing the possibility for children to be active at higher frequencies might be more motivating in intervention studies than increasing the duration of activities. Distinct periods during the day in terms of the intensity of activity have been reported earlier[30,32,33] and were similar to the present study. Lunchtime and evening periods were defined by a high proportion of stationary activities and a low proportion of running and jumping, and evening periods by a low proportion of walking, indicating that this time was used for recovery. Walking was equally distributed between 6:00 and 8:00 AM and between 12:00 AM and 2:00 PM, which might be due to the way to school and it was equally distributed between 10:00 and 12:00 AM and between 2:00 and 4:00 PM, which might be due to the way home from school. These times coincided with the diary setting "walking," indicating the similarity of the diary and the classification procedure in assessing this activity. In addition, a considerable amount of running and jumping was found during this activity setting, indicating the importance of covering distances by foot, which is even more important as the number of children walking to school was found to be high in our region due to the short distances to school.[11] The proportion of running and jumping was elevated between 10:00 and 12:00 AM, which coincides with the diary settings "PE lessons" and "school break," indicating their influence on high-impact activity types that might be important for physical fitness and bone health.[6,21] During the afternoon, when running and jumping were elevated according the classification system, time was spent in PE lessons between 2:00 and 4:00 PM, and in vigorous outdoor activity (2:00–6:00 PM) according to the diary. Indoor and outdoor sport training, which mainly took place between 4:00 and 8:00 PM, might have elevated especially the jumping activity. Therefore, the classification procedure revealed crucial periods during the day for different activity types, which is important for the description of PA in children. Simultaneously detecting the setting of such activities might be crucial for possible interventions aimed at these periods.

Description of the activity diary setting by classification procedure

When the activities assessed by the activity diary were analyzed by the classification procedure, the proportion of time spent in running and jumping was the highest in PE classes, vigorous outdoor activity, and outdoor sport training. These results are similar to the results reported by Bringolf-Isler et al,[27] who found higher average accelerometer counts during the same diary settings. Therefore, PE and playing or sport training performed outdoors are settings that lead to more active time in children. High-impact activities such as running and jumping, but also walking, were increased during these settings. In contrast to the study by Bringolf-Isler et al,[27] where the level of the average accelerometer counts in indoor training was reported to be lower than in "vigorous outdoor activity" and "walking," we found that some of the most intense activities occurred during vigorous indoor training.

This can be explained by the difference in the sampling rate, as playing indoors might contain a considerable amount of very short bursts of intense activity that may not have been adequately registered by the per-minute analysis in the study of Bringolf-Isler et al.[27] However, the absolute time spent in walking, running, or jumping during the diary setting "vigorous indoor activity" was very low (10 minutes/week), indicating that activities such as outdoor sport training (48 minutes/week), PE (26 minutes/week), and vigorous outdoor activities (27 minutes/week) are more important for accomplishing active time. A considerable amount of absolute active time was accumulated during the diary setting "general low activities." However, this was the setting in which children spent most of their time (55 hours/week). To accumulate more activity efficiently, it seems to be more favorable to send children to play or train outdoors, or to oblige them to go to PE lessons. At school, which was one of the settings within "general low activities," a lot of active time was accumulated over time. Therefore, it might be favorable for PA to increase short-term activity during these hours by active breaks or by combinations of exercise and theoretical content. It can be concluded that the present classification procedure can be used to investigate diary-assessed activity settings on a more objective basis. In addition, the present classification procedure provides a potential to add further information to activity diaries to ascertain additional information such as the amount of different types of activity, in order to investigate the possible effects of interventions in greater detail.

This study offers the first detailed insights into the duration, frequency, and the amount of time children spend in different activity types while living in their natural environment. The classification procedure used, which was validated with field data,[24] has been applied for the first time to accelerometer data collected during an entire ordinary school week with the aid of a portable, nonobtrusive accelerometer system. The results obtained by this system are comparable with those from detailed observational studies. Its practicability in the field is superior in terms of the slight impact on the participants and the low time resources required compared with observational studies, and could therefore be applicable to studies with large sample sizes. In addition, the classification procedure facilitates analysis at the individual level. This procedure has considerable potential for challenging observational measurements in analyzing the complex pattern of children's PA in free-living conditions.

This study is limited by its small sample size. Applied to the data of a representative sample, the results of the classification system might change according to the children's respective activity behavior. The mean activity level of the children included in the present study (girls: 526.2 counts/minute, boys: 675.5 counts/minute) was, however, within the range of activity measured in 9- and 15-year-old boys and girls in a large European accelerometer study,[13] indicating that the children in the present study were comparable with larger study samples in terms of mean activity levels. Wearing a second device increases the burden for the participant. However, during the development of the classification procedure, using a second device was reported to increase the recognition rate by 23% using the major vote classifier.[24] A further limitation of the present study is that the temporal comparison of the diary and accelerometer information is limited by the accuracy of the self-report measurements in the diary. Furthermore, this study does not provide any information on the intensity of activity. However, the analysis of each activity type with the cut-off method revealed that one activity type might belong to several intensity classes underlining that the two methods focus on different aspects of PA. The recognition of the type of activities is important for recommendations and interventions that focus on certain health factors, such as bone health, as activities such as running, jumping, skipping, or stair walking provide high impacts and favor the enhancement of bone mineral accrual.[6,21] In interventions that promote a certain activity type, such as walking to school, it would be possible to determine whether an increase in PA was reached by children who were formerly driven to school by car or by those who cycled to school before the intervention. Including activity-type specific information has recently been found to improve the estimation of energy expenditure models in children.[20] Future studies should try to combine classification procedures, such as that used in the present study, in combination with intensity estimation.

The aim this study was to demonstrate the potential of a classification procedure for future studies and to give insight into the nature of PA in children. The results of this study provide comprehensive information about the duration, frequency, and type of PA in children under field conditions. The information provides assistance in generating effective PA interventions based on an objective understanding of children's PA behavior.

Conclusion

The classification procedure used in this study allows for an investigation of the PA type, duration, and frequency, thus showing the potential of such methods for analyzing PA in children. This procedure provides insight into the highly transitory nature of children's activity by demonstrating that the bouts of activity are considerably shorter than previously reported. This study enhanced the understanding of different aspects of children's activity on different weekdays and at different periods of the day and during various activity settings by applying a classification procedure to accelerometer data. The procedure's most important utility for future studies, however, is that it provides detailed results that are comparable with those of observational methods, while being less time and labor intensive.

Conflicts of interest

The authors declare no conflicts of interest.

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